Abrupt glacial climate change – a phenomenon of extreme winters?

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Scientists from IFM-GEOMAR and Utrecht University found that the rapid climate variations in the North Atlantic region at the end of the last ice age were mainly a phenomenon of extreme winters. The summer seasons were only marginally effected.

The last glacial period from 70,000 to 10,000 years ago, defined as Marine Oxygen Isotope Stage (MIS) 2-4, was punctuated by abrupt climate changes, switching within a few decades between warm (interstadials) and cold stages (stadials) that lasted for a few thousand years. These abrupt changes – called Dansgaard-Oeschger events named after two Danish resp. Suisse climate researchers - are intensively studied in order to improve our knowledge about the climate system behaviour and especially to provide insights into how climate system responses and interactions can be expected to occur in the future.

In a recent study, published in the journal *Nature Geoscience* in 2008, geoscientists from IFM-GEOMAR and Utrecht University (The Netherlands) suggest that the rapid glacial cooling events in the North Atlantic region are an expression of dramatic winter conditions rather than a reflection of summer cooling. Hence, an extreme seasonality is postulated for the glacial period.

Abrupt glacial climate changes have first been documented in high resolution through the analysis of Greenland ice cores and demonstrate how large and rapid these changes were: the average air temperature warmed by up to 16°C within two to three decades. These abrupt changes were related to changes in the Atlantic meridional overturning circulation, which is part og the global ocean circulation and primarily driven by differences in water density.

In many cases perturbations and even shutdowns in the meridional overturning circulation were postulated in the past during periods of increased meltwater influx from the northern hemisphere continental ice sheets, deepwater formation in the North Atlantic ceased with the consequence that the northward heat transfer to the high northern latitudes was dramatically reduced. The North Atlantic cooled with dramatic effects for the NW-European climate. Based on the recognition of these cooling events a scenario was recently discussed in which a reduction of sea surface salinity and hence, in the overturning circulation in response to anthropogenic global warming may eventually lead to severe cooling in NW-Europe in the near future.

In their new study, the paleoceanographers from Kiel and Utrecht present sea surface temperature (SST) reconstructions from the northeastern Gulf of Mexico for the last 300,000 years to examine the regional and seasonal expression of millennial-scale climate variability. The Gulf of Mexico represents an ideal location to decipher the dynamic evolution of the Atlantic Warm Pool (AWP), an ocean area in the equatorial western Atlantic and the adjacent Caribbean with extremely high sea surface temperatures. In summer, when warm Caribbean surface waters enter the Gulf *via* the Loop Current, the entire Gulf heats up and forms part of the AWP. The Loop Current transporting ~30 Sv (10^6 $m^3 sec^{-1}$) of water through Yucatan and Florida Straits mediates the oceanic heat and salt flux from the Caribbean Sea into the Atlantic Ocean. Its interference with the Mississippi River discharge is in fact critical for both the regional climate in the Gulf of Mexico area and the heat and water vapor transport towards high northern latitudes.

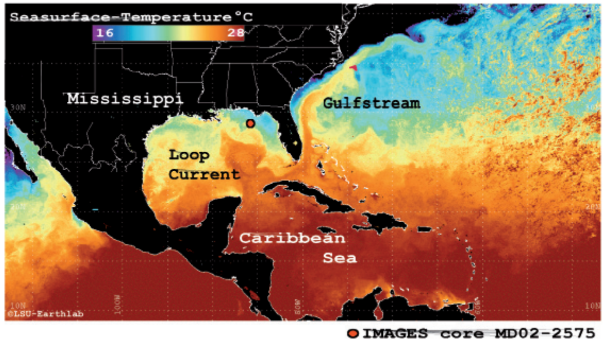

Figure 1. Chart showing sea surface temperatures in the Caribbean and the Gulf of Mexico (from LSU Earthlab). Note the warm water transfer into the gulf via the Loop Current. The location of the paleoceanographic record studied here is indicated.

During boreal winter, warm Caribbean surface water generally does not penetrate into the northeastern Gulf and tropical waters are restricted to a narrow band in the southeastern Gulf. During this time, relatively cool

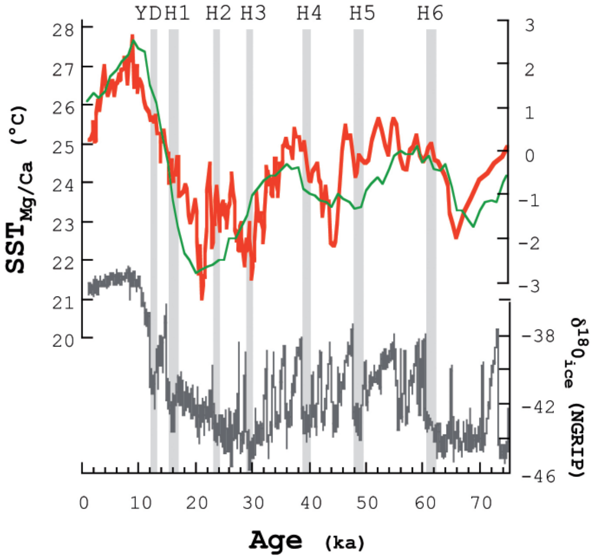

Figure 2. The northeastern Gulf of Mexico SST record (red) over the last 75 ka in comparison to the Greenland climate record (gray). The close match of the SST record to the summer insolation variability (green) implies a persistent summer expansion of the Atlantic Warmpool during abrupt cold events and hence, an extreme seasonality during glacial MIS 3.

Gulf of Mexico Common Water characterizes the uppermost 200 m owing to increased vertical convective mixing induced by cold meteorological fronts that propagate from the North American continent over the Gulf.

The described seasonal contrast is particularly strong in the northeastern Gulf region and results in an intra-annual SST variability ranging from a minimum of 19.6°C in February to a maximum of 29.7°C in August. This variability is closely related to the seasonal position of the Intertropical Convergence Zone (ITCZ), which is the tropical rain belt. Today, both the ITCZ and the northern boundary of the AWP reach their northernmost positions during boreal summer.

The new Nature Geoscience study shows that the expansion of the AWP into the Gulf of Mexico did not respond to the glacial abrupt climate oscillations. This is in contrast to records from the southern Caribbean that do show a strong response to the North Atlantic rapid cooling. These records reflect past (northern hemisphere) winter conditions. The obvious seasonal bias of the Gulf of Mexico SST record towards the summer season supports an idea according to which the abrupt cooling events during MIS 2-4 were predominantly a winter phenomenon.

One possible explanation for this seasonal bias could be that during winter, the North Atlantic was close to a threshold temperature at which sea ice is extensively formed: during the rapid cooling events, the reduced transfer of tropical heat towards the high latitude North Atlantic made it across this temperature threshold and subsequently sea ice grew over large parts of the North Atlantic. The vast sea ice cover and its cumulative effects on the albedo functioned as a fridge for the high latitudes. During summer the threshold, instead, was not passed and therefore the cooling effect was commonly small and compensated.

The study has interesting implications for the effect of a potentially weakened thermohaline circulation in response to the today´s global warming. As the modern “warm” North Atlantic is far from such a winter threshold temperature, the cooling effect will be much less and not comparable to those glacial cooling events. A “Day after tomorrow scenario” becomes, in view of our findings, unlikely. The new study also highlights the need for a comprehensive network of quantitative paleoclimate records monitoring the spatial seasonal change to understand the full variability of the climate system.

How do paleoceanographers in fact reconstruct ocean temperatures and salinities? Since a couple of years, the temperature-sensitive incorporation of magnesium into the calcitic skeletons of marine planktonic microfossils (protozoa, foraminifera) selected from ocean sediments is used to assess SST with an accuracy of approximately ±0.5°C. This geochemical approach was initially suggested by GEOMAR scientists, and became meanwhile a widely applied and internationally accepted paleoceanographic tool. In combination with the detection of stable oxygen isotopes in the same foraminiferal shells it became possible to even reconstruct SSS (sea surface salinity) reliably.

Reference:

Ziegler, M., D. Nürnberg, C. Karas, R. Tiedemann, and L.J. Lourens, 2008: Persistent summer expansion of the Atlantic Warm Pool during glacial abrupt cold events. *Nature Geoscience*, **1**(9), 601-605, doi 10.1038/ngeo277.